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WADC TECHNICAL REPORT 54-391
SUPPLEMENT 1

INVESTIGATION ON NOTCH SENSITIVITY OF HEAT-RESISTANT ALLOYS AT ELEVATED TEMPERATURES

Supplement 1 — Apparent Volume Increase Due to Triaxial Stresses

CAPT. W. E. DIRKES

MATERIALS LABORATORY

JANUARY 1956

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PROJECT No. 7360

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Metals Branch and was initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques", Task No. 73605, "Design and Evaluation Data for Structural Metals", formerly RDO No. 605-227 SR-3a, "High Temperature Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Capt. W. E. Dirkes acting as project engineer.

This report covers period of work from July 1954 to November 1954.

ABSTRACT

The volume of structural metals is generally considered to remain constant even with extremely high stresses applied. Some data recently published indicate significant changes in volume under stress-rupture test conditions for specimens having stress gradients. More recent analysis of the same data and specimens together with additional measurements from these specimens show that significant volume changes did not actually occur, but that plane cross-sections of specimens did not always remain plane when subjected to stress gradients.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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SUPPLEMENT 1 - APPARENT VOLUME INCREASE DUE TO TRIAXIAL STRESSES

I PURPOSE

WADC Technical Report 54-391 reported apparent volume increases in notched stress rupture specimens approaching 10 percent of the original volume of the notched section for a single specimen of S-816 heat resistant alloy. A series of measurements was subsequently undertaken to determine whether or not a volume increase occurred.

II GENERAL CONSIDERATIONS

Mechanics of materials are based upon a number of fundamental assumptions, one of which is that the volume of structural materials, even under extremely large loads, remains practically constant. Indications of ± 1 percent change in volume would not upset previous theories of fracture. The 10 percent volume increase of notched sections of stress-rupture test specimens reported in WADC Technical Report 54-391 cannot be considered to be due to errors in measurement. Some more fundamental reason must be involved in this observation. Volume increase of this magnitude, if proven, would be of great interest to personnel investigating time dependent characteristics of materials.

III FACTUAL DATA

Figure 21 from WADC Technical Report 54-391 reproduced herein as Figure 1 shows the notch contours of a notch before and after time-deformation at elevated temperature. Three notches were contained on a single axial load specimen for which Figure 1 was prepared so the test conditions were identical for each notch. Root radii of 0.005, 0.010 and 0.060 inches indicated volume increases of 9.2, 11.7 and 7.8 percent, respectively, when computed from the data published. Similar notch contour measurements were made on specimens of S-816 and Inconel X-550 subjected to stress-rupture test conditions. Measurements were made on notched portions of unbroken test specimens with a shop microscope. Measurements were made on four sides

of some specimens. Complete notch contours were determined. The stress-rupture characteristics of the materials under consideration are reproduced from Figures 4, 5 and 7 of WADC Technical Report 54-391 as Figures 2, 3 and 4 of this report to show the comparative test conditions for each specimen used for volume determinations.

Volume determinations were obtained by measuring notch contour areas with a planimeter, computing equivalent radii and calculating the volume of the related right circular cylinder. Results were checked by dividing each notch into a series of rings and repeating the calculations. In addition, results were checked by using the volume calculation procedure outlined in WADC Technical Report 54-391. The results of the calculations are contained in Table I, which also lists the nominal stress and time to rupture for each specimen. Correlation of the data in Table I and locations on the stress-rupture plots of Figures 2, 3 and 4 show that the apparent volume increases reported are not a function of stress, time or notch sensitivity. However, rather large deformations are indicated for S-816, and practically none for Inconel X-550. The amount of apparent volume increase corresponds to the relative ductility of the two materials. Waspalloy with ductility between that of S-816 and Inconel X-550 was found to have apparent volume increases in the range of 1.5 to 3.0 percent.

The apparent volume increases noted would naturally suggest corresponding density decreases. Density measurements of S-816 resulted in a value of 8.67 for the untested material and 8.73 for the notched section of specimen S-20 after test. The lack of confirmation of volume change by density measurements indicates that some mechanism other than volume increase must be operating to provide the indications obtained in WADC Technical Report 54-391.

The method of computation of volume assumes that plane cross-sections of notched specimens remain plane when the specimen is deformed. The data presented indicate the possibility that originally plane sections, subjected to stress gradients which extend above the elastic stress limit, do not remain plane. In order to check this possibility, a notched specimen of S-816 alloy was ground flat parallel to the axis on two sides to obtain a notched flat specimen 0.14 inches thick. Lines perpendicular to the specimen axis were scribed across the notched section and the specimen was subjected to 50,000 psi nominal axial stress for 50 hours at 1350°F. Figure 5 shows the deformation of the originally straight grid lines. Considerable deviation of the plane sections represented by the scribed lines is evident, even at locations considerably removed from the notch root.

The stress distribution in notched bar specimens is not linear, and as materials are stressed such that the highest stresses reach the inelastic range defined by the stress-strain curve, the strains would be expected to distribute non-linearly. A detailed analysis of this stress condition for creep tests is presented in WADC Technical Report 54-175, Part 2.

IV CONCLUSIONS

Supplementary data obtained after the release of WADC Technical Report 54-391 indicate that no appreciable volume change occurred in the test materials under the experimental conditions used. The measurements which were taken indicating an apparent volume increase are believed to be correct, but a proper interpretation of the data is believed to be that originally plain sections of notched specimens of ductile material may distort appreciably when partially plastic load conditions are imposed. The amount of deformation of plain sections is related to the ductility of the material as well as the stress gradients imposed.

TABLE I

APPARENT VOLUME CHANGE IN NOTCHED STRESS-RUPTURE SPECIMENS

Specimen Number	Temperature °F	Stress PSI	Rupture Time, Hours		Notch Radius	Volume Change, Percent
S-17	1350	50,000	89.1	D	.005	9.2
S-17	1350	50,000	89.1	D	.010	11.7
S-17	1350	50,000	89.1	D	.060	7.8
S-20	1600	27,000	14.6		.060	8.1
S-27	1500	30,000	79.8		.060	7.7
I-13	1350	60,000	30.1		.005	1.5
I-13	1350	60,000	30.1		.045	NIL
I-13	1350	60,000	30.1		.100	NIL
I-18	1600	18,000	358.7		.045	NIL
I-22	1350	35,000	197.4		.045	NIL
I-22	1350	35,000	197.4		.100	NIL
I-25	1350	65,000	42.4		.100	NIL
I-27	1350	40,000	157.1		.100	NIL
I-34	1600	25,000	64.6		.045	NIL
I-57	1350	40,000	138.5		.020	3.0

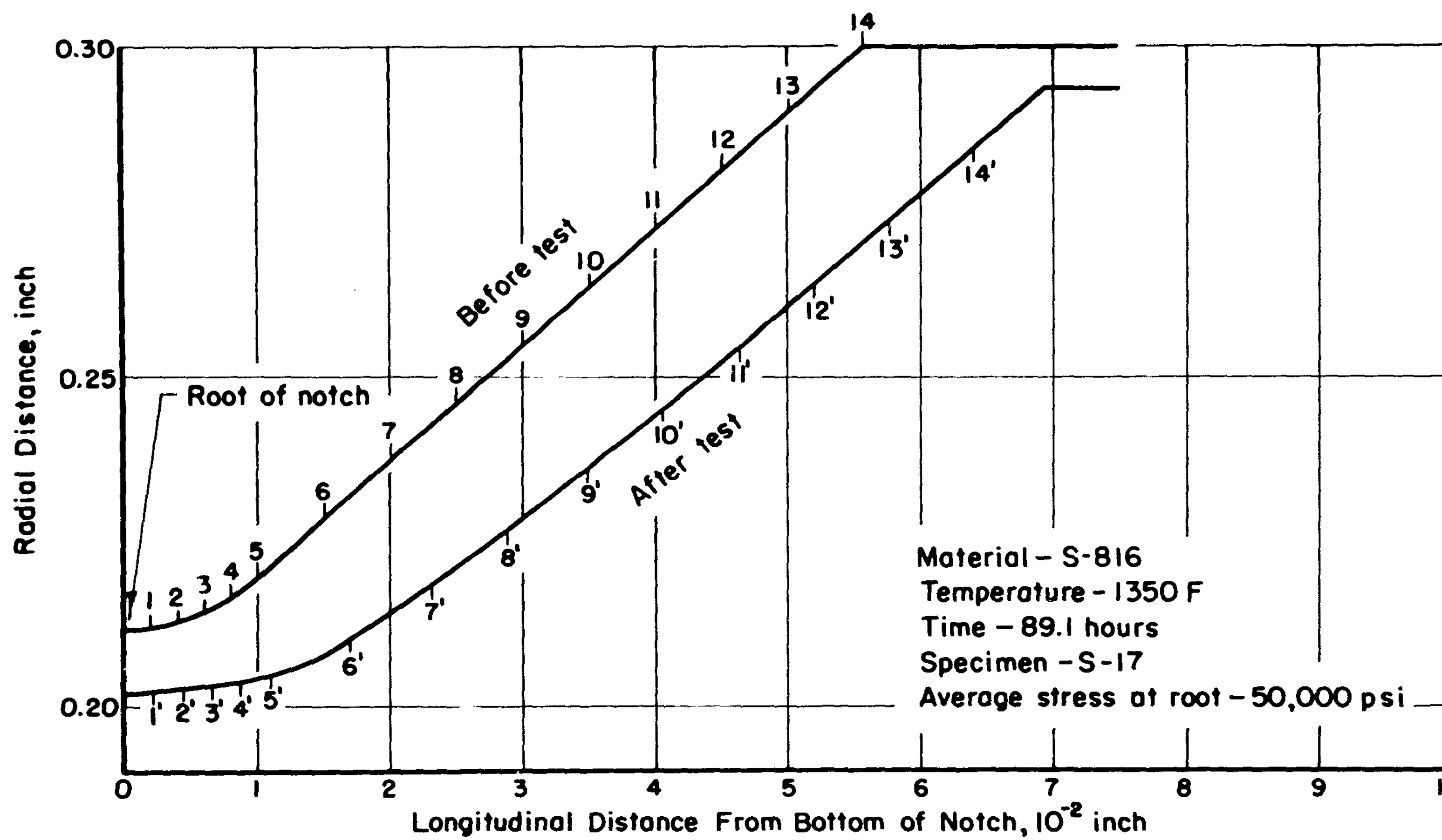

FIGURE 1, UNDEFORMED AND DEFORMED NOTCH CONTOURS FOR 0.010-INCH RADIUS NOTCH

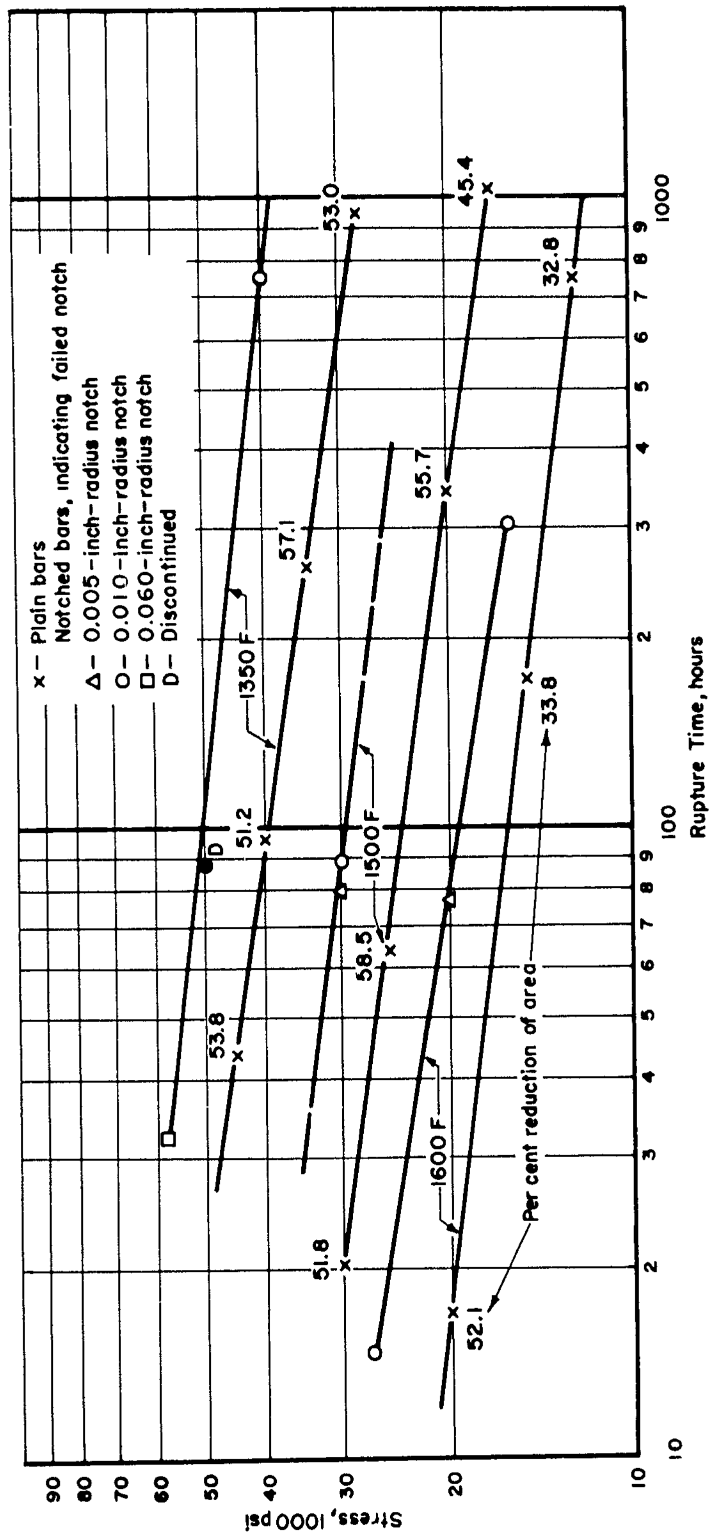

FIGURE 2. STRESS VERSUS RUPTURE-TIME CURVES FOR PLAIN AND NOTCHED BARS OF S-816 ALLOY

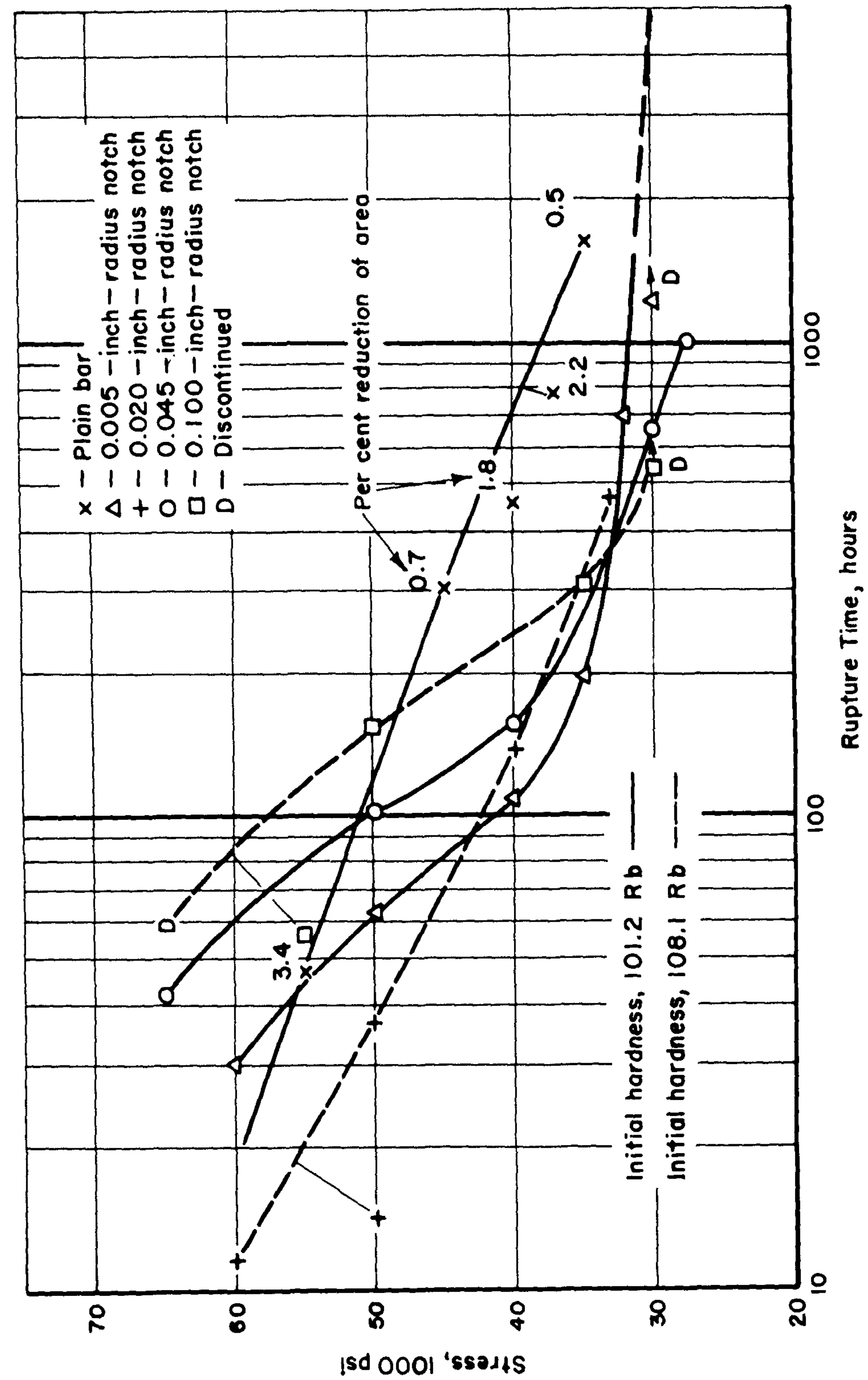

FIGURE 5. STRESS VERSUS RUPTURE TIME FOR INCONEL "X" TYPE 550 ALLOY AT 1350 F

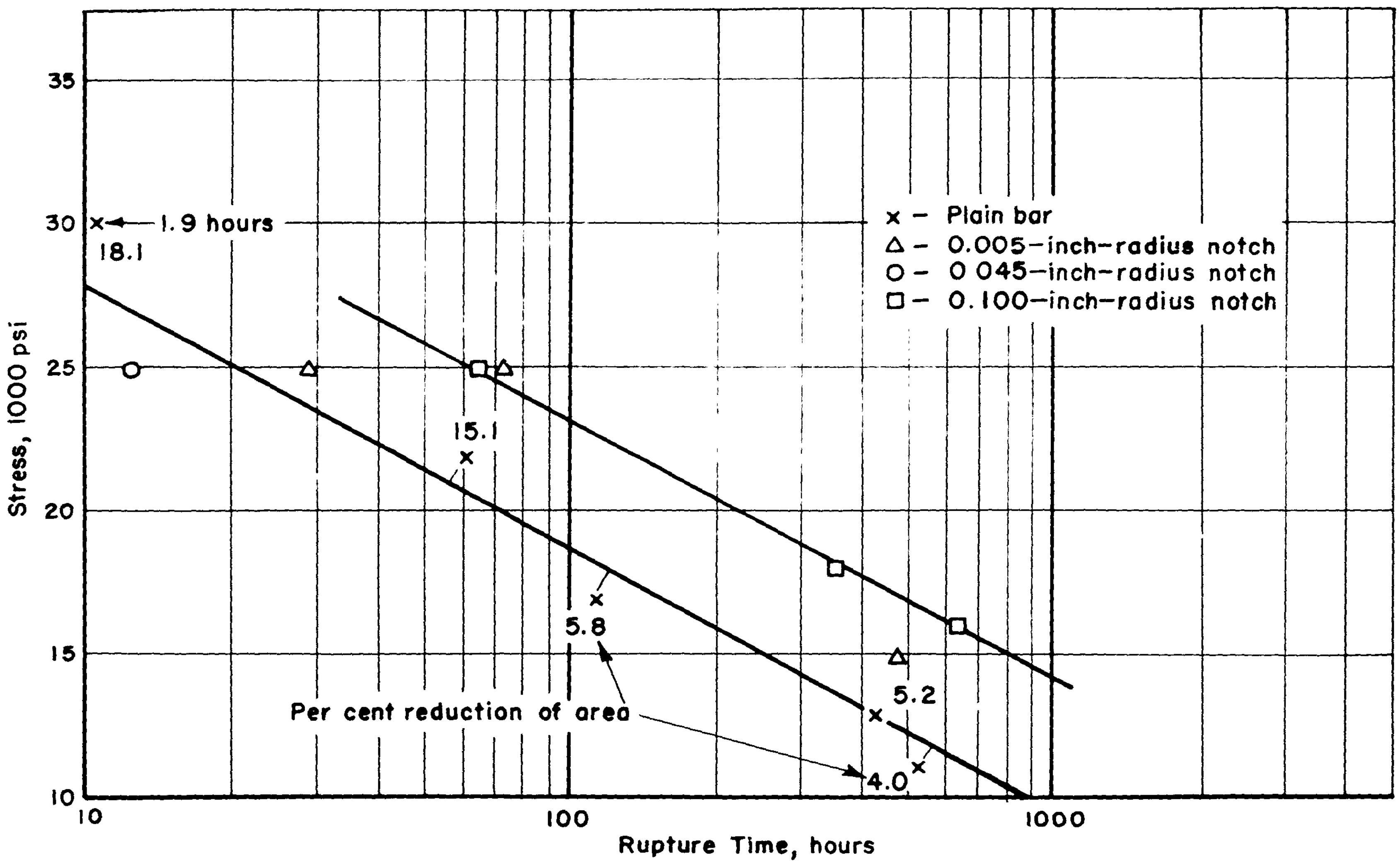

FIGURE 4. STRESS VERSUS RUPTURE TIME FOR INCONEL "X" TYPE 550 ALLOY AT 1600 F

FIGURE 5. CHANGE OF SHAPE OF PLANE CROSS-SECTIONS AS INDICATED BY DEFORMATION OF SCRIBED LINES.